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Effect of the plasma-forming gas consumption on processes of plasma spray coating and metal powder production

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Abstract. The influence of the plasma-forming gas consumption on the plasma flow velocity and its turbulence intensity is analyzed. Full-scale experiment conducted to confirm the results of the mathematical experiment. Comparative analysis of the results of practical and theoretical experiments showed satisfactory convergence. As a result of the study, developers and consumers of equipment are offered recommendations for improving the technology.

1. Introduction

Plasma torches allow you to apply metal coatings, as well as produce metal powders. The actual task of developers and consumers of technological equipment is to determine the effect of influencing factors on the result and the process of operation of plasma torches. An important factor is the prediction of the result during regulating the influencing factors. Understanding the role of influencing factors allows equipment operators to control the properties and quality of the final product. For example, customers of metal powders have the following requirements: chemically homogeneous, non-porous spherical particles, the size of which ranges from 20 microns to 100 microns. In turn, special requirements are imposed on metallic coatings: adhesion, strength, and wear resistance. Plasma spraying method (or pulverization) of a metal billet (bar, wire) is used to obtain powders (or coatings) from titanium and its alloys, stainless steel, and others [1].

The speed, temperature and intensity of the turbulence of the plasma flow are the main factors influencing the processes of obtaining powder and creating metal coating. Among the parameters that determine the change of the above factors plasma-forming gas consumption plays an important role [2]. The purpose of this work is to determine the dependence of the velocity and intensity of turbulence of a plasma jet on plasma-forming gas consumption. To achieve this goal, the SolidWorks software package was used, which allows implementing solutions by the finite element method [3].

In the Institute of Metallurgy of the Ural Branch of the Russian Academy of Sciences a plasma installation has been developed and is operational for coating and produce powders. The section along the axis of the plasmatron head part, included in this installation, to demonstrate the profile of the parts forming the shape of the internal channel, is presented in figure 1.

2. Creating a computer model of the process and conducting a mathematical experiment

The solid-state three-dimensional mathematical model was created that adequately describes the



working plasmatron and the temperature and flow velocity along the plasma jet axis were determined. The geometrical parameters of the model, the type of gas environment are selected in accordance with those used in the existing laboratory installation. The initial data used in the simulation by the finite element method are: gas type – argon (introduced through the swirlers), gas consumption – 50 l/min; initial incremental gas pressure – 1.5 atm; the initial plasma temperature is 7000 K. The design of the plasmatron consisted of the anode with a conical confusor section with a diameter transition from 11 to 8 mm (from D_H to D) and an anode confusor part length 58 mm. The results are presented in figure 2.

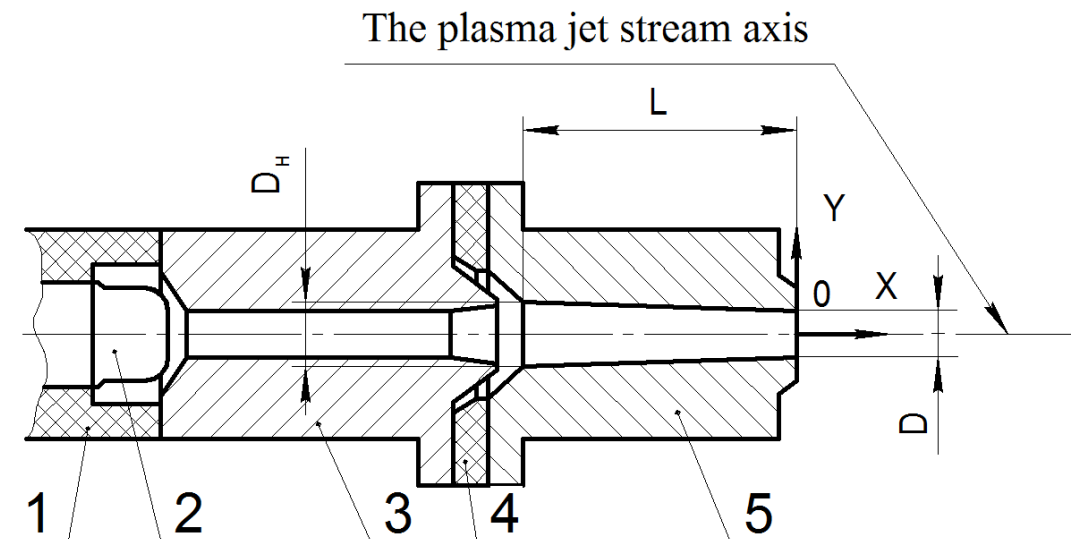


Figure 1. Sectional diagram along the axis of the plasmatron head part: 1 – gas swirler; 2 – cathode; 3 – interelectrode insert; 4 – gas swirler; 5 – anode; D_H – the diameter of the inlet to the anode confusor part; L – The length of the anode confusor part; D – the anode outlet diameter. XOY – auxiliary coordinate system.

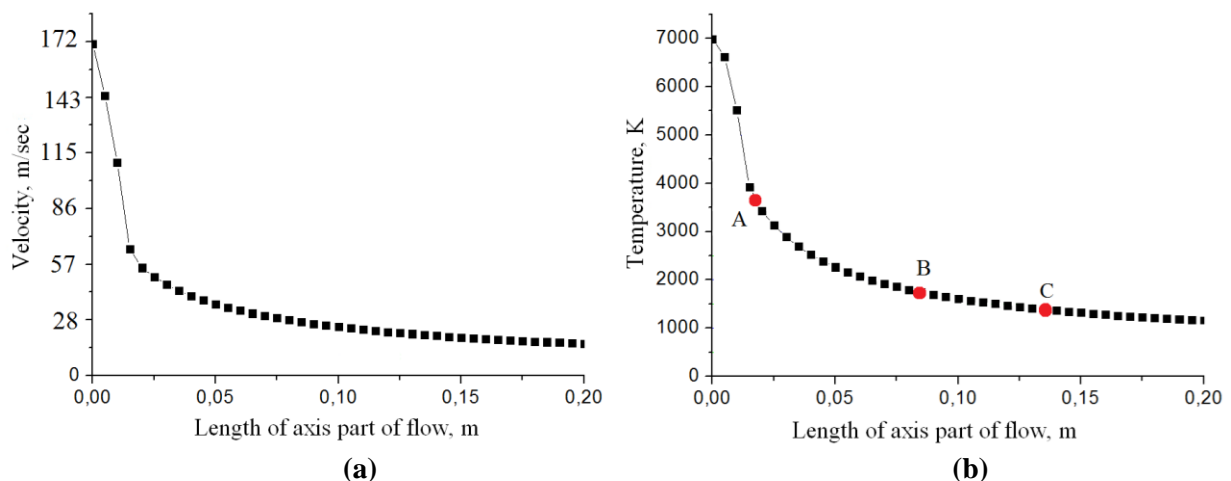


Figure 2. The desired quantities dependence along the plasma flow axis of plasmatron: (a) – the flow velocity; (b) – the flow temperature. According to practical experiment: point A (tungsten), point B (steel), point C (copper).

The applied software package allows determining the distribution patterns in given sections of the numerical value of the considered quantities. As a result of the science research, distribution patterns in

cross section, passing along the plasma stream flow axis, were considered. Figure 3 shows the diagram in cross section for temperature distribution.

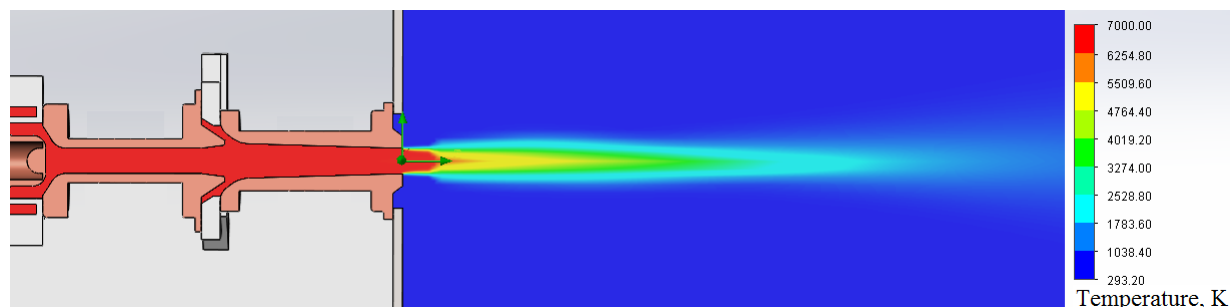


Figure 3. The plasma jet temperature distribution.

3. Description of the full-scale experiment and verification of the theoretical results of a computer experiment

In order to verify results of the theoretical experiment, a full-scale experiment was conducted to establish the temperature value on the axis of the plasma jet stream at the exit of the plasmatron at three points. Three rods were selected for this, each had a diameter of 3 mm. Selected rods had different melting points, the following rod materials were selected for this: copper M1 GOST 859-2014 (copper melting point M1 is 1084°C), Steel 10 GOST 1050-88 (melting point Steel 10 is 1485°C) and lantanized tungsten TU 48-19-27-88 (the melting point of lantanized tungsten is 3380 °C).

The rods were alternately placed in the manipulator transversely to the axis of the plasma jet flow in such a way that one end of the rod was on the axis, and the other was clamped in the manipulator. The manipulator was located at a distance of 0.5 m from the plasmatron. Further, the manipulator with the rod mounted in it, gradually moved with a constant speed of 50 mm/min parallel to the axis of the plasma flow towards the plasmatron. The distance from the rod to the end plane of the anode (plasmatron output) was recorded.

An optical pyrometer was also used in the full-scale experiment (type EOP-66 No. 240 GOST 5.278), which measured the surface temperature of the rod free end. At the moment when the melting process began to occur on the surface of the rod, the data from the pyrometer scale were taken and the distance from the rod to the plasma torch was recorded. Parameters of the gas consumption and its type corresponded to the data used in the theoretical experiment. Three parallel natural experiments were conducted. Results were averaged and compared with results of a theoretical experiment. The data presented in table 1 and figure 2(b).

Table 1. Distances from the rod to the anode end surface of the plasmatron when the melting temperature on its surface is reached according to the results of theoretical and full-scale experiments.

Material	Theoretical experiment (mm)	Full-scale Experiment (mm)	Measurement Error (%)
Copper M1	141	135	4,4
Steel 10	82	85	3,5
Lantanized tungsten	19	20	5,0

Comparative analysis of the results of full-scale and theoretical experiments showed satisfactory convergence.

4. Study of the effect of the plasma-forming gas consumption on the plasma flow velocity and its turbulence intensity

Based on the mathematical model that has been developed and tested as a result of a full-scale experiment, an analysis was made of the gas consumption influence on the velocity and turbulence

intensity at a characteristic point. The characteristic point is taken as the point O (the beginning of the auxiliary coordinate system of figure 1). The range of gas consumption was chosen from 10 l/min to 100 l/min with a step of 10 l/min. The following was taken as the initial data: gas type – argon; gas pressure – 1.5 atm; initial plasma temperature is 7000 K.

As a result of parametric analysis based on three independent theoretical experiments, an average value of the desired quantities was obtained depending on the consumption of the plasma-forming gas. The results are presented in figure 4.

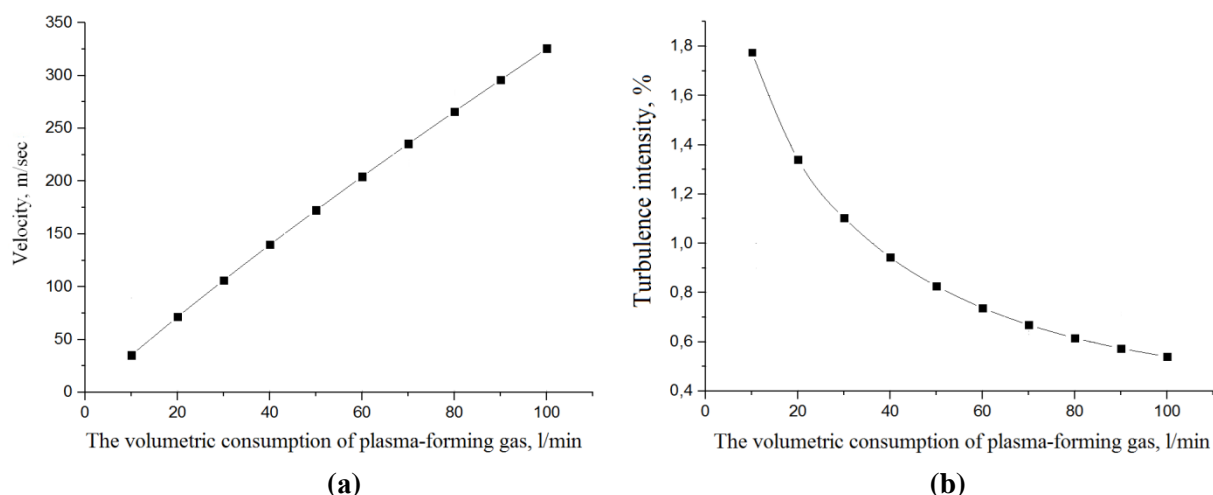


Figure 4. Graphs of dependencies of the desired quantities at a characteristic point on the plasma-forming gas consumption for the cases: a – the plasma flow rate; b – intensity of turbulence.

The graphs presented in figure 4 showed that the dependence of the velocity of the current medium on the volume plasma-forming gas consumption is direct and the dependence of the intensity of turbulence on the volume plasma-forming gas consumption is reverse.

5. Conclusions

As a result of the study, it was concluded that an increase in the volume flow rate of the plasma-forming gas makes it possible to increase the velocity of the plasma flow. The increase in speed has a positive significance for metal coating processes and a negative one in metal powder production processes. As the intensity of turbulence increases, the opening angle of the plasma torch increases. Consequently, a reduction in the intensity of turbulence leads to a reduction in the size of the sputtering spot, and in the case of the production of powder products to a reduction in the range of particle size distribution. These recommendations provide practical benefits for developers and consumers of technological equipment.

Acknowledgment

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